

## Introduction

During the CRYSTAL-FACE field mission, water vapor was measured *in situ* by the JPL Laser Hygrometers (JLH), two small and lightweight near-infrared laser spectrometers, on both the ER-2 and WB-57F aircraft platforms [Herman et al., 2002; May, 1998]. The objective was to provide accurate and precise data for studying ice cloud microphysics, formation, evolution, persistence, and dissipation. As stated in the NRA, "Accurate water vapor measurements are particularly important since many of the issues concerning cloud effects on the water budget hinge on accurate relative humidity determination."

### What is the latest state of the JLH data?

There has been a significant change from the preliminary data (July 2002) to the revised data (Feb. 2003). The new values are higher by typically 30% at 200 hPa, and by 50% at 100 hPa. These data were reduced using calibrations that R. L. Herman recently performed at Harvard University in collaboration with the Harvard water group.

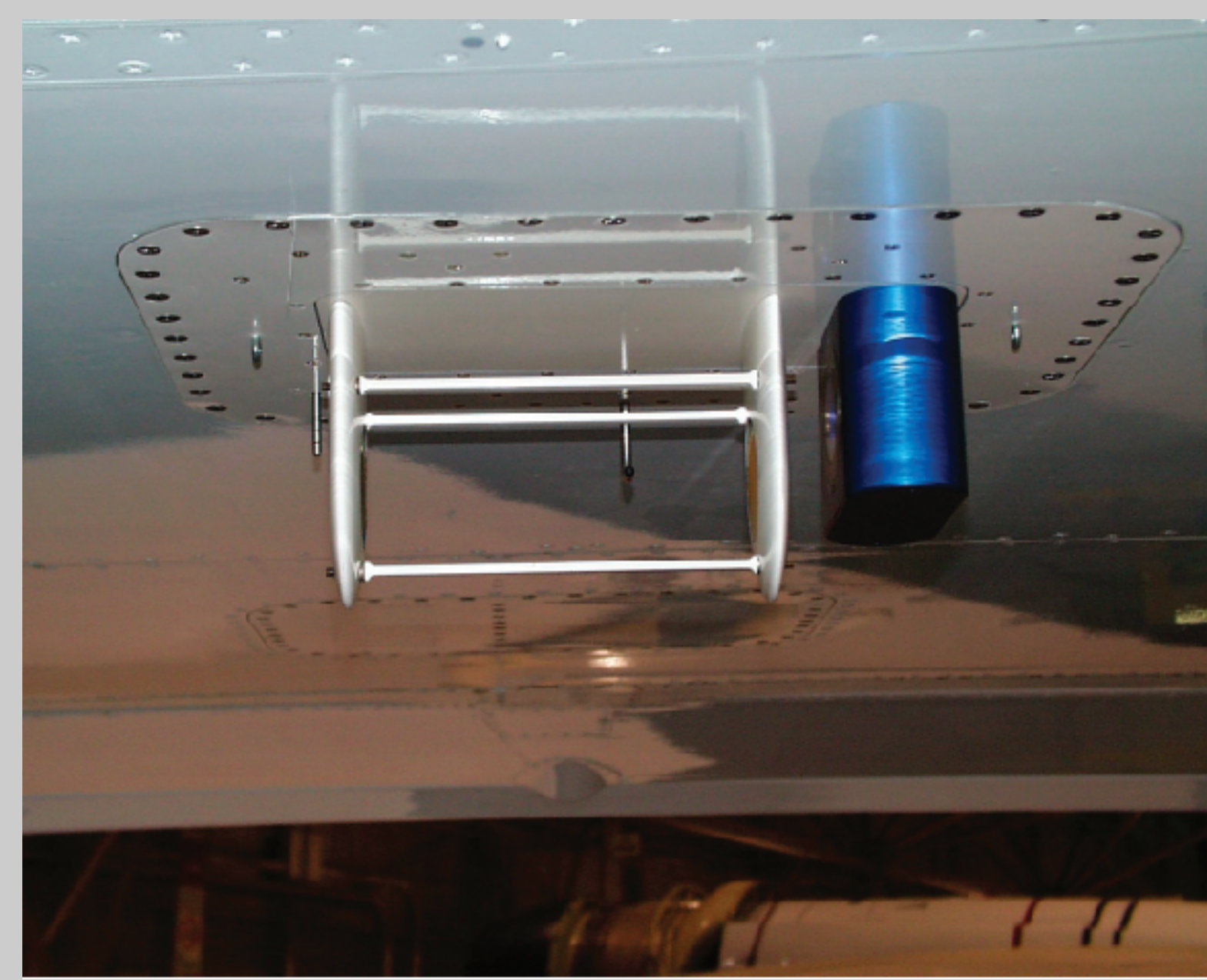


Figure 1. The JPL Laser Hygrometer on the WB-57F aircraft. *Right:* The blue housing contains the tunable diode laser, detector and lenses. *Left:* The white fiberglass forms and invar spacer rods hold the open-path, multi-pass Herriott cell. The laser beam is reflected multiple times between the two mirrors to achieve an 11.13-m optical pathlength in the free airstream.

### Why was there a change?

The JLH laser burned out on 11 May 2002 due to overheating on the ground prior to takeoff of the WB-57F. The replacement laser operated at a higher wavenumber ( $7306.7\text{ cm}^{-1}$ ) than the original one ( $7299\text{ cm}^{-1}$ ), scanning a different water absorption line (Figure 4). Thus, we had to recalibrate JLH at JPL in June 2002, and again after the field mission. The new laser was more temperature-sensitive than the original one, leading to different performance characteristics on the ground than in flight.

## Laboratory Calibration

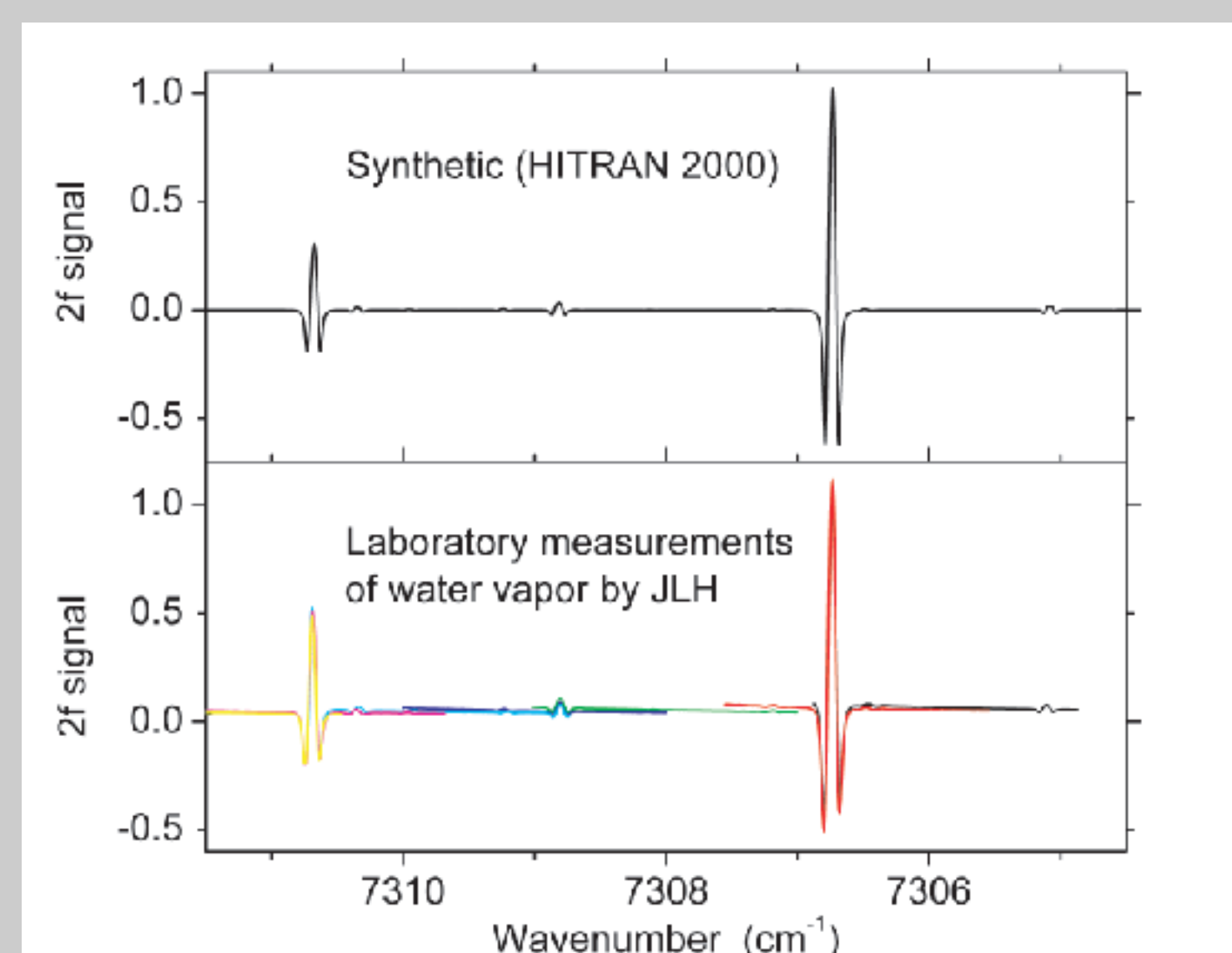


Figure 4. The spectral region utilized by JLH in the near-infrared (1.369 mm). *Top:* synthetic second-harmonic spectrum of water vapor (G. J. Flesch, JPL) generated using parameters from the HITRAN 2000 linelist. *Bottom:* water vapor spectra recorded by JLH in the laboratory. In flight, the tunable diode laser scans across the strongest line (red) at  $7306.7\text{ cm}^{-1}$ .

JLH is calibrated in the laboratory by flowing mixtures of air with trace water through the instrument over a range of pressures. The open-path sample cell is sealed with an aluminum hermetic tube that is placed between the mirror holders (Figure 5), and a wedged window with o-ring seal on the laser side of the mirror holders. The dead space between laser housing and mirrors is purged with dry nitrogen. The water mixing ratios in the gas cylinders are frequently checked with a NIST-traceable, General Eastern 1311DR chilled-mirror frostpoint hygrometer (Figure 5) operating at 1 atm pressure and 1 slpm flow rate.

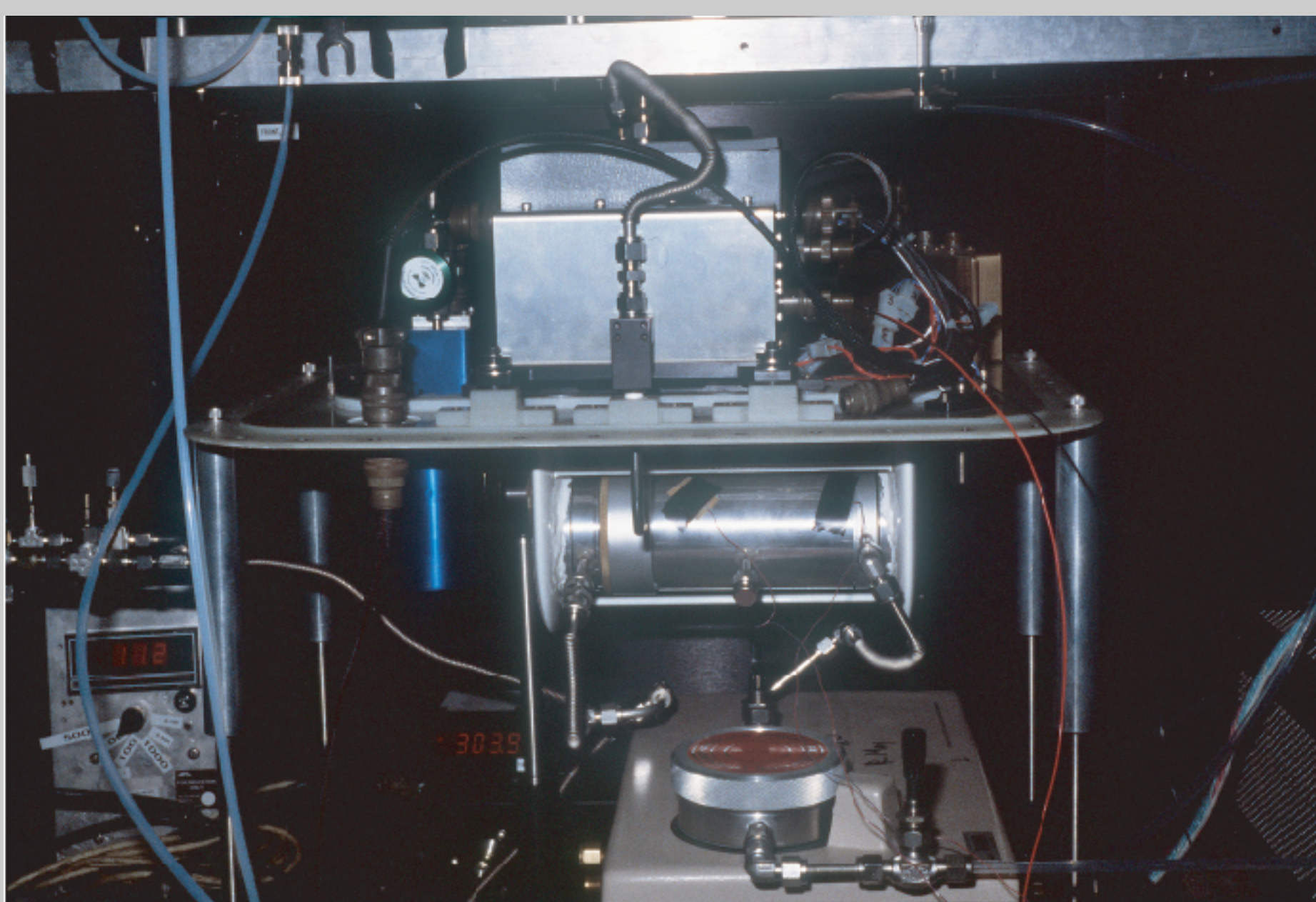


Figure 5. Laboratory calibration of JLH at JPL. *Center:* Between the instrument mirror holders (white) is a hermetic aluminum tube. *Bottom center:* the gas cylinder water concentration is checked with a frostpoint hygrometer.

## Cross-calibration: JLH, Harvard Water, and CLH

To address accuracy issues with the CRYSTAL-FACE data, JLH was recently cross-calibrated with the Colorado Laser Hygrometer (CLH, P.I. L. Avallone) and the Harvard Water instruments. CLH was brought to JPL for simultaneous measurements of water vapor with JLH. Air with trace water was flowed through both instruments in parallel over a wide range of pressures (Figure 6).

Next, JLH was taken to Harvard University for cross-calibrations with their instruments. JLH made measurements of water vapor under a wide variety of pressures, flow conditions, and water mixing ratios. These calibrations were based on simultaneous direct-absorption measurements of water vapor at near-infrared ( $7306.7\text{ cm}^{-1}$ ) and ultraviolet wavelengths (see Elliot Weinstock's poster). First, we performed flow through both instruments in parallel. Flow was turned on for typically five minutes to allow the system to equilibrate. Then, both instruments were reconfigured for flow in series (first Harvard, then JLH). The ratio of water measurements (Harvard direct absorption over JLH) was found to be systematically different for series and parallel configurations (Figure 7). We had more confidence in the series measurements, so a scaling was applied to JLH data based on the series flow. An additional pressure correction (to account for errors in the spectral parameters) was applied based on the parallel flow as a function of pressure. This pressure correction is the reciprocal of the ratio shown in Figure 7.

Figure 8 shows water vapor mixing ratios from (black line) JLH with the laboratory corrections applied, and (red squares) Harvard UV axial absorption measurements. Slight differences between JLH and Harvard indicate that a more thorough calibration correction needs to be applied to the JLH data. In particular, nonlinearities at mixing ratios greater than 200 ppmv will be reexamined in the near future.

## Accuracy

The level of agreement of JLH with Harvard Water Vapor and Harvard Total Water instruments is typically 5-10% (see poster by E. M. Weinstock). However, these instruments report significant supersaturation in visible aircraft contrails (Figure 2). Both theory and previous measurements [Heymsfield et al., 1998] indicate that such contrails, with small (1-mm) ice particles in concentrations up to several hundred per cc, should be very close to 100% relative humidity with respect to ice. This issue remains unresolved.

## Precision

The flight precision of JLH is better in the upper troposphere than in the stratosphere because the signal-to-noise ratio increases with water concentration. It is uncertain, though, whether small changes in upper tropospheric water reflect instrument precision or natural variability. As an upper limit estimate of precision, we examine water variability during a high-altitude stratospheric segment of the 3 July 2002 WB-57 flight (Figure 3). At pressures less than 74 hPa and  $72860 < \text{UTC} < 73530$  sec, tracers are relatively constant and the 1-s standard deviation of JLH water is:

- 1.3-sec data: 0.087 ppmv (archived),
- 2.0-sec data: 0.073 ppmv,
- 10-sec data: 0.053 ppmv.

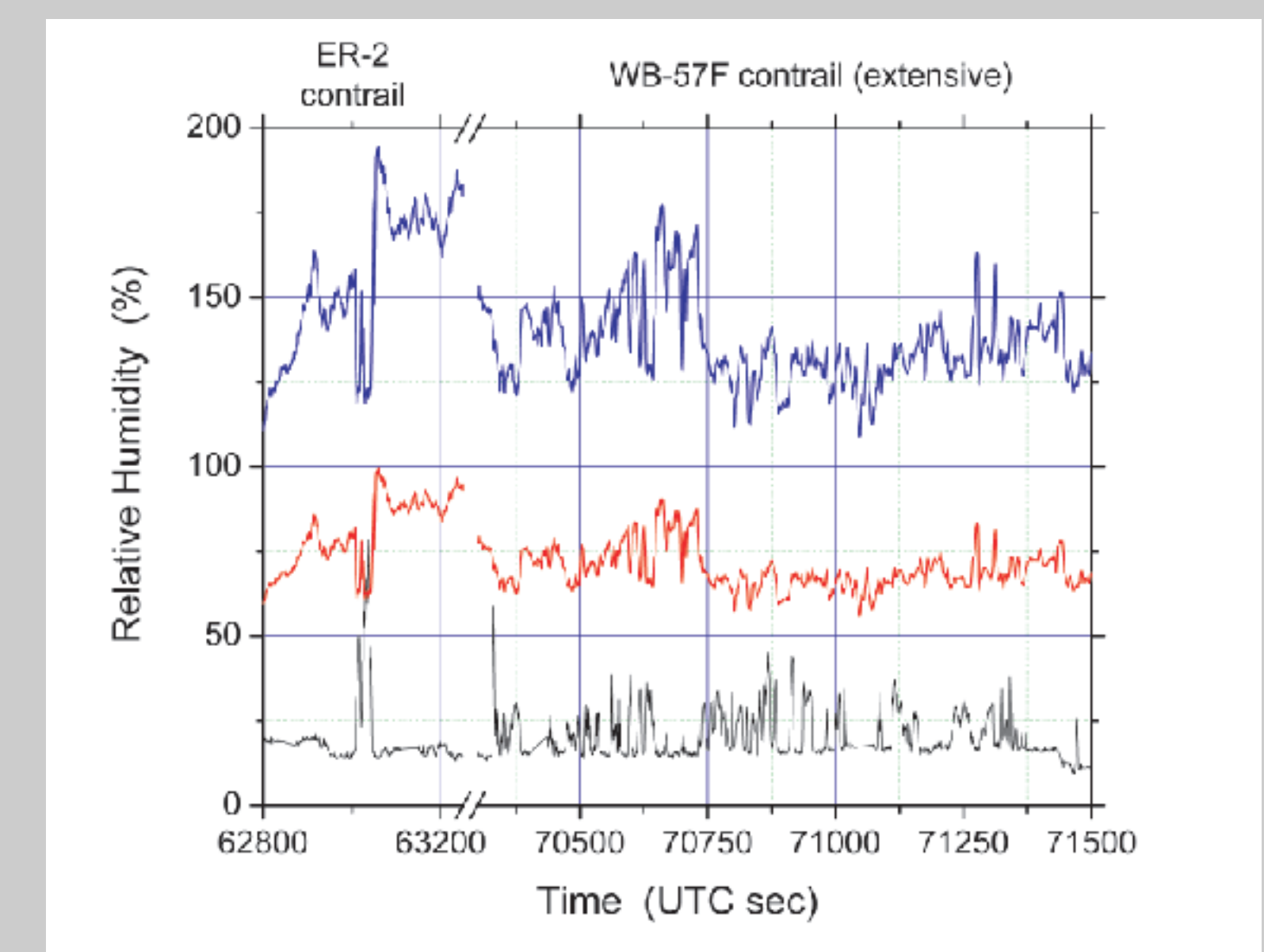


Figure 2. The WB-57F intercepted visible aircraft contrails on 13 July 2002. *Blue:* JLH relative humidity with respect to ice. *Red:* same, with respect to liquid. *Black:* NCAR NO (\*0.02), courtesy of B. A. Ridley.

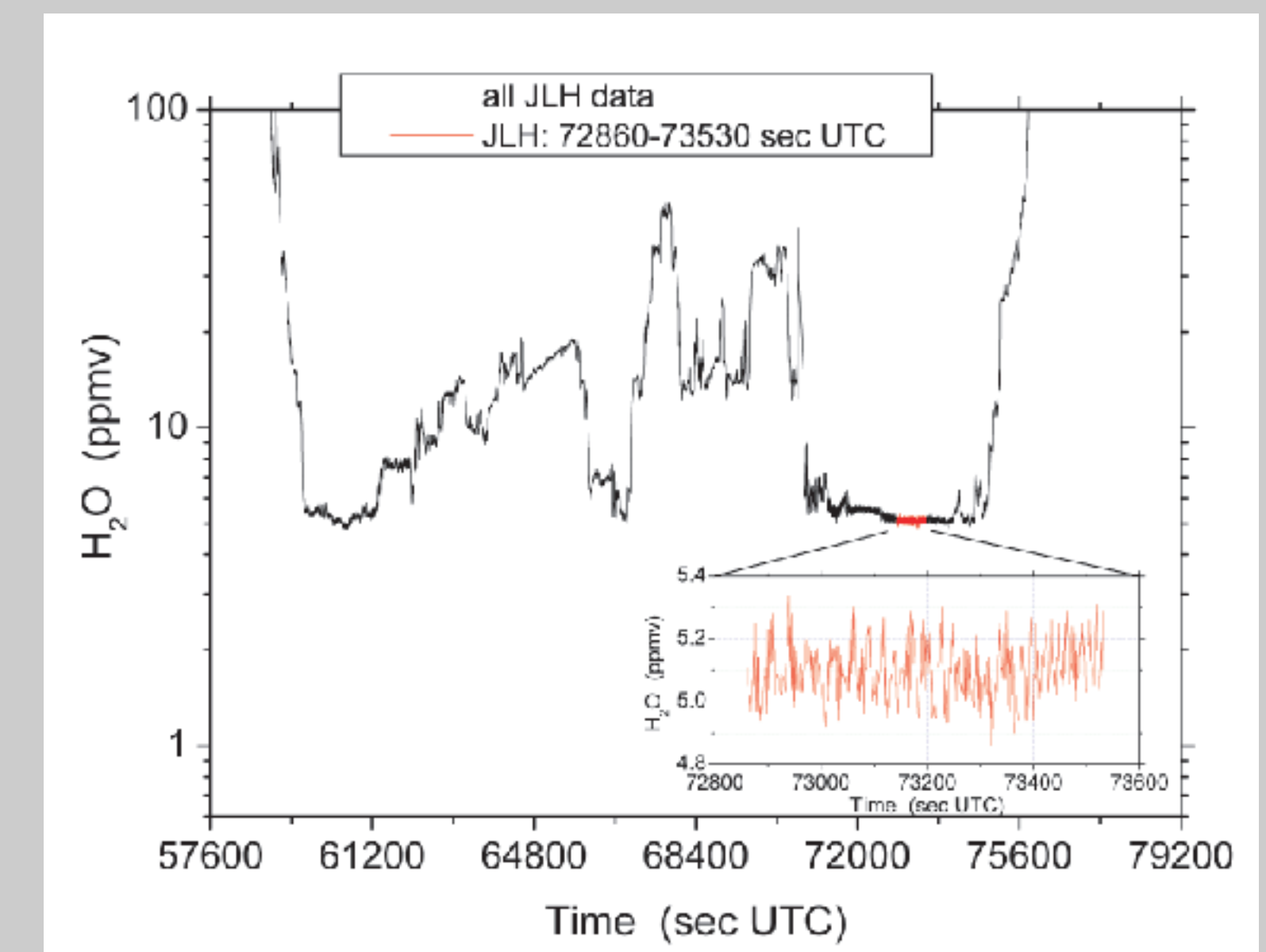


Figure 3. *Black:* JLH water vapor volume mixing ratios from the 3 July 2002 WB-57 flight. *Red:* The highest altitude portion of the flight, 71 to 74 hPa. *Red insert:* These same data are enlarged to show the precision of 1.3-sec stratospheric data.

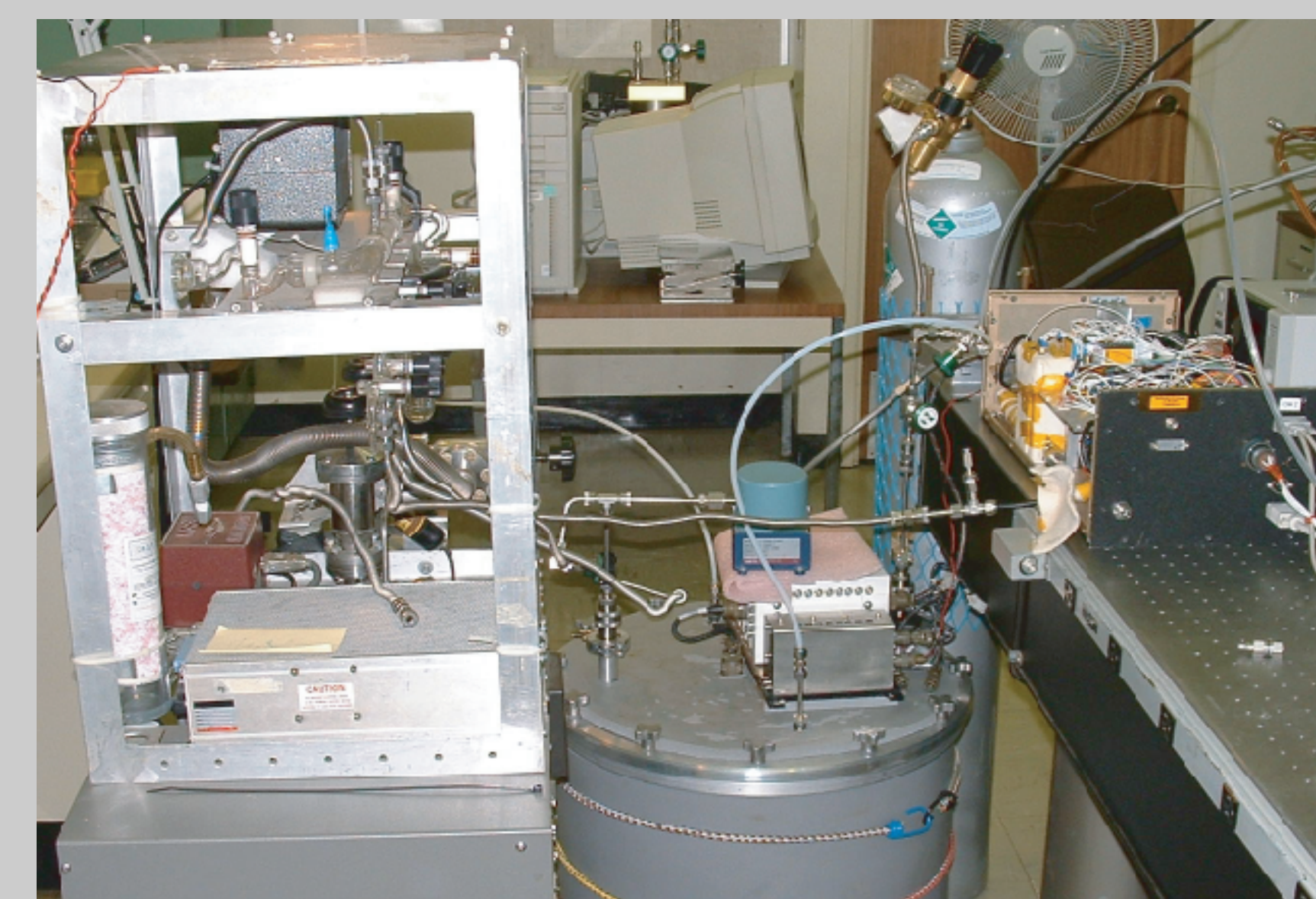


Figure 6. Cross-calibration of JLH and CLH (courtesy of L. Avallone). JLH is completed enclosed in a pressure vessel (center) that is purged with dry nitrogen. CLH is resting on top of the optical table (right). The source of water is the gas cylinder (upper right), which contains air with 41.6 ppmv water (checked with the General Eastern frostpoint hygrometer). The gas flows through both instruments in parallel.

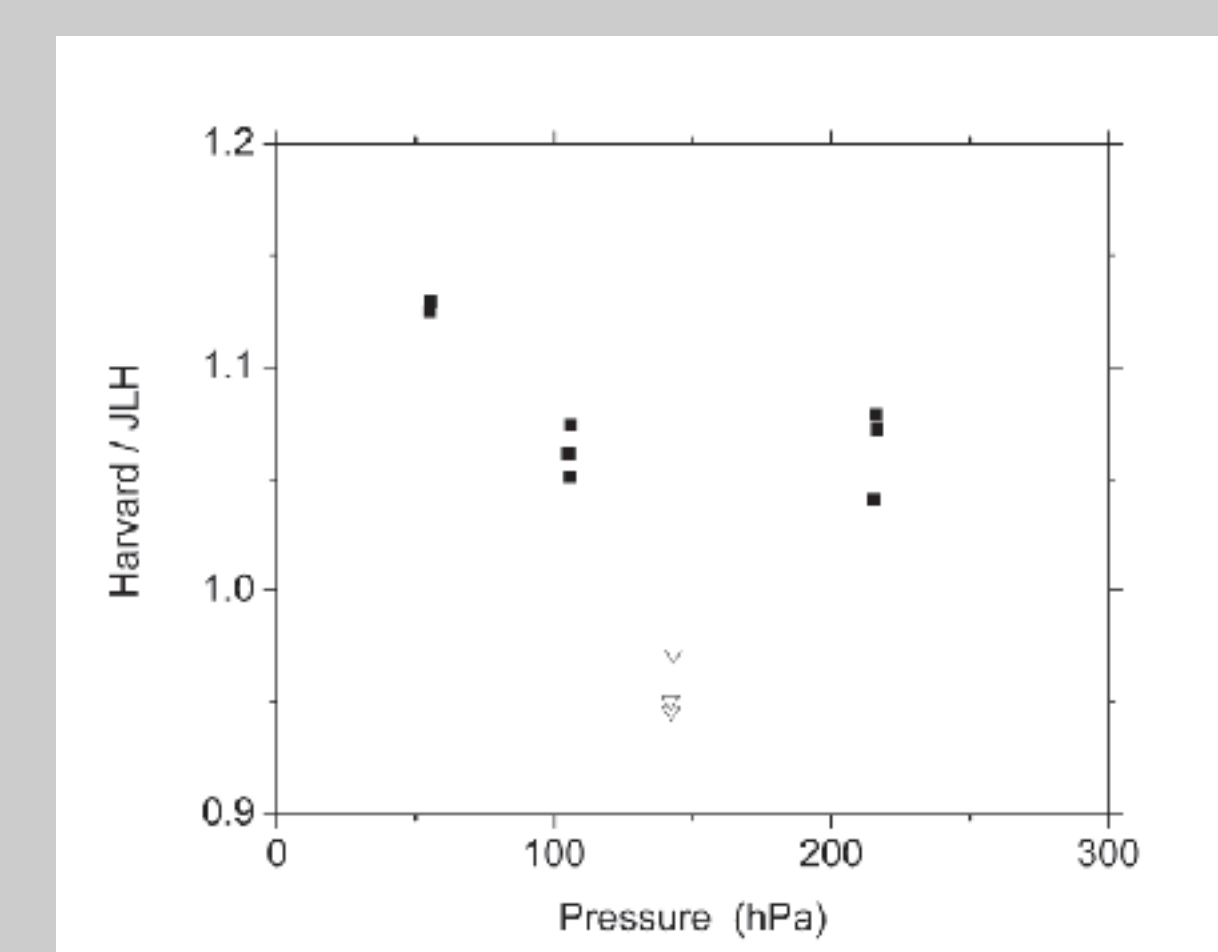


Figure 7. *Solid squares:* Ratio of Harvard UV axial absorption measurements of water vapor to raw JLH water vapor volume mixing ratio (minus background water) for flow in parallel. *Open triangles:* the same ratio for flow in series (Harvard data courtesy of E. M. Weinstock).

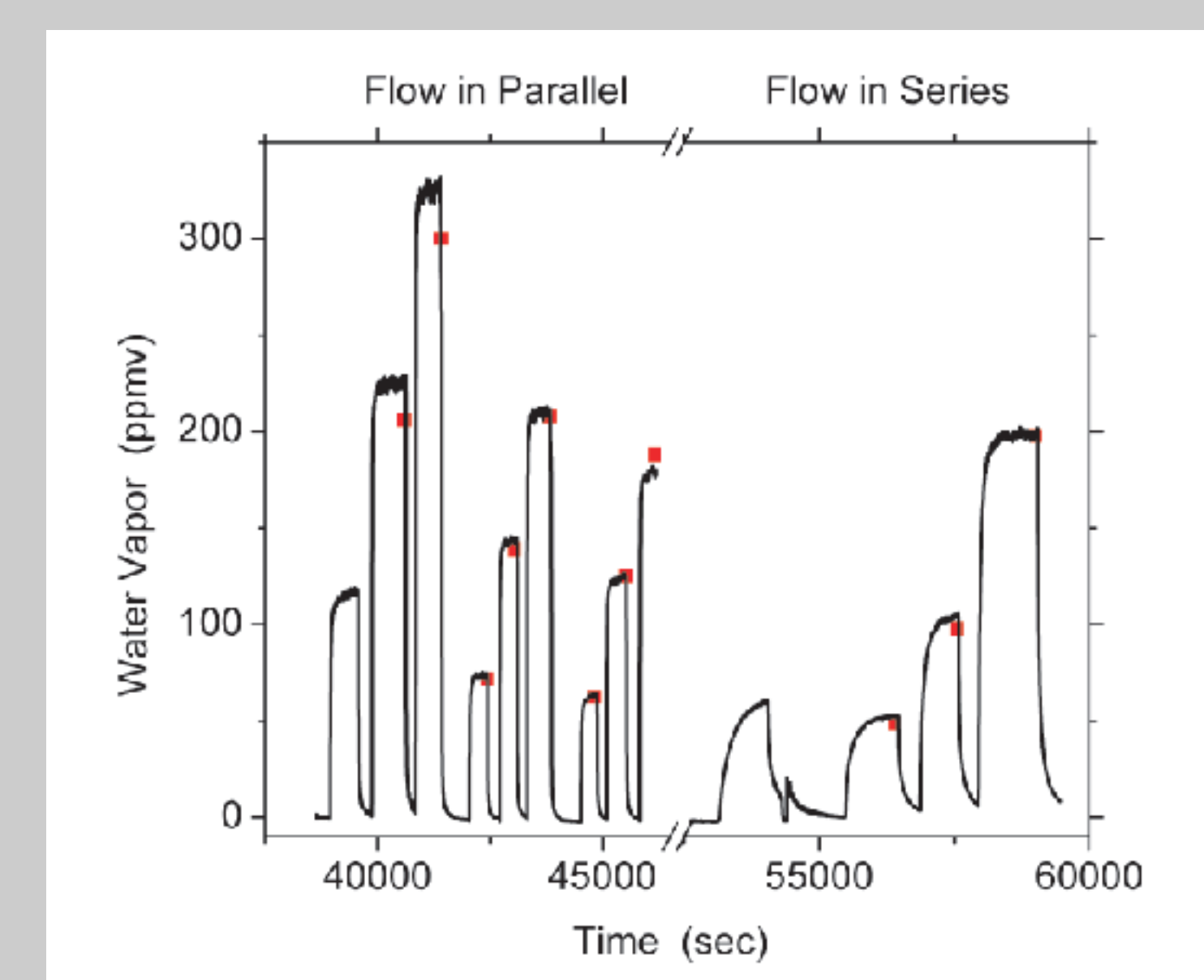


Figure 8. *Black line:* JLH water vapor volume mixing ratio (minus 5 ppmv background water) after pressure correction is applied. *Red squares:* water from Harvard UV axial absorption measurements (E. M. Weinstock).

## Conclusions

JLH, Harvard Water and Total Water, and CLH are tied together by cross-calibrations. The revised JLH flight data agree with Harvard Water to ~5 to 10%. JLH and both Harvard instruments agree in dry air despite different detection techniques, temperatures, and flow conditions. This supports the validity of these instruments, which have historically been in close agreement [Kley et al., 2000; Hintsa et al., 1999]. Nevertheless, there remain important questions about the accuracy of humidity measurements within aircraft contrails.

## Future Work

- 1) Continue to quantify uncertainties due to P, T, Mach number, pitch angle, laser properties, and spectral line parameters.
- 2) Compare JLH(WB-57) with JLH(ER-2) during the 13 July 2002 intercomparison.
- 3) Better quantify the background amount of water in the Harvard lab calibrations.
- 4) Determine why JLH and Harvard diverge slightly at volume mixing ratios > 200 ppmv.
- 5) Continue laboratory measurements at JPL to compare with those taken at Harvard.
- 6) Recalibrate the instruments under a wider range of conditions (50 to 500 hPa).

## References

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